Chapter 7. Agricultural Wind Erosion

AP-42 does not include a section on agricultural wind erosion. Thus, the methodology adopted by the California Air Resources Board (CARB) is presented as the primary emissions estimation methodology in lieu of an official EPA methodology for this fugitive dust source category.

This section was adapted from Section 7.12 of CARB's Emission Inventory Methodology. Section 7.12 was last updated in July 1997.

7.1 Characterization of Source Emissions

Wind blowing across exposed nonpasture agricultural land results in particulate matter (PM) emissions. Windblown dust emissions from agricultural lands are calculated by multiplying the process rate (acres of crop in cultivation) by an emission factor (tons of PM per acre per year).

7.2 Emission Estimation: Primary Methodology[1-12]

The standard methodology for estimating the emission factor for windblown emissions from agricultural lands is the wind erosion equation (WEQ). Although the WEQ is well established, it is controversial. The WEQ was developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) during the 1960s, for the estimation of wind erosion on agricultural land.[4,5] The U.S. EPA adapted the USDA-ARS methodology for use in estimating windblown PM emissions from agricultural lands in 1974[6], and the California Air Resources Board (CARB) adopted the U.S. EPA methodology in 1989.[1]

The USDA-ARS has been conducting ambitious programs over the past decade to replace the WEQ with improved wind erosion prediction models such as the Revised Wind Erosion Equation (RWEQ)[7] and the Wind Erosion Prediction System (WEPS)[8] models. CARB does not consider these models feasible for use, although certain portions of the RWEQ were incorporated into the CARB methodology in 1997. According to CARB, the WEQ (with modifications) continues to be the best available, feasible method for estimating windblown agricultural emissions.

7.2.1 Summary of CARB's Wind Erosion Equation (ARBWEQ)

Much of the controversy surrounding the WEQ has related to its tendency to produce inflated emission estimates. Some of the reasons for the inflated emissions relate to the fact that it was developed in the Midwestern United States, and that it does not take into account many of the environmental conditions and farm practices specific to the West. In the revised methodology developed by CARB (referred to as the ARBWEQ), CARB staff added adjustments to the WEQ to improve its ability to estimate windblown emissions from western agricultural lands.

The U.S. EPA modified the USDA-ARS derived WEQ in 1974 as follows:[6]

$$E_S = AIKCL'V' \quad (1)$$

where, E_S = suspended PM10 fraction of wind erosion losses of tilled fields (tons/acre/year)
A = portion of total wind erosion losses that would be measured as suspended PM10, estimated to be 0.025
I = soil erodibility (tons/acre/year)
K = surface roughness factor (dimensionless)
C = climatic factor (dimensionless)
L' = unsheltered field width factor (dimensionless)
V' = vegetative soil cover factor (dimensionless)

The A factor in Equation 1 has been used in the ARBWEQ without modification. There has been concern that this factor doesn't take into account finite dust loading. The RWEQ[7] and WEPS[8] models are attempting to address that concern. The soil erodibility factor, I, was initially established for the WEQ for a large, flat, bare field in Kansas. Kansas has relatively high winds along with hot summers and low precipitation. The K, C, L' and V' factors serve to adjust the equation for applicability to field conditions that differ from the original Kansas field. The PM2.5/PM10 ratio for windblown dust from agricultural land published by CARB is 0.222.[3]

In the WEQ, the soil erodibility factor, I, is a function of soil particle diameter, which can be estimated for various soil textural classes from Table A-1 of the above-referenced U.S. EPA methodology.[6] The soil textural classes were determined by CARB staff from University of California soil maps.[9] An additional level of detail was included in the ARBWEQ by using the United States Department of Agriculture-Natural Resources Conservation Service's (NRCS) State Geographic Data Base (STATSGO) of soil data.[10] In addition, the USDA-ARS recommended an adjustment for changes to long term erodibility due to irrigation.[11] This affects a property known as cloddiness, and refers to the increased tendency for a soil to form stable agglomerations after being exposed to irrigation water.

The surface roughness factor, K, reflects the reduction in wind erosion due to ridges, furrows, and soil clods, and is crop specific. The values for K were derived from Table A-2 in the above-referenced U.S. EPA methodology.[6] Similar crops were assigned similar surface roughness values.

The annual climatic factor, C, is based on data that show that erosion varies directly with the wind speed cubed, and as the inverse of the square of surface soil moisture. For the ARBWEQ, CARB staff improved the input data, as well as the methods associated with developing the county wide averaged annual climatic factor. Monthly climatic factors were obtained by modifying the annual climatic factor calculation method.

Figure A-5 in the above referenced U.S. EPA methodology[6] allows the calculation of the unsheltered field width factor, L', from the unsheltered field width, L, and the product of erodibility, I, and surface roughness, K. The values for the unsheltered field width, L, were derived from Table A-2 in the above referenced U.S. EPA methodology.[6] Similar crops were assigned similar unsheltered field width values.

The vegetative soil cover factor, V', is especially problematic for California, and was completely replaced by a series of factors in the ARBWEQ (see analysis below). This factor assumes a certain degree of cover year round based upon post harvest soil cover, and does not account for barren fields from land preparation, growing canopy cover, or replanting of crops during a single annual cycle. All of these factors are very important in the estimation of windblown agricultural dust emissions. Therefore, CARB staff replaced the vegetative soil cover factor, V', with separate crop canopy cover, post harvest soil cover, and post harvest replant factors.

7.2.2 Climate-Based Improvements in the ARBWEQ

The calculation of the climatic factor C requires mean monthly temperature, monthly rainfall, and mean annual wind speed for a given location as data inputs. This factor is used to estimate climatic effects on an annual basis. In order to make estimates of emissions using the ARBWEQ that are specific to different seasons, it is necessary to estimate the climatic factor that would apply to each season. The changes to the agricultural windblown emissions inventory discussed here, include modifications to both the annual and the monthly climatic factor profile determination methodology included in the ARBWEQ.

The Annual Climatic Factor for the ARBWEQ. Page 157 of the above referenced U.S. EPA document[6] includes a definition of the climatic factor which agrees with the method utilized by the NRCS.[12] It incorporates the monthly precipitation effectiveness derived from precipitation and temperature, along with monthly average wind speeds. Garden City, Kansas is assigned a factor of 1.0 and the climatic factors for all other sites are adjusted from this value.

The Monthly Climatic Factor for the ARBWEQ. There are several ways to create a climate-based monthly profile for the ARBWEQ. Because the ARBWEQ is an annual emission estimation model, CARB staff did not directly estimate monthly emissions using the monthly climatic factor. Instead, the annual climatic factor was used to determine annual emissions, and then the monthly normalized climatic factors were multiplied by the annual emissions. This helped to limit the effect of extreme monthly values on the annual emissions estimate. CARB staff devised a method termed the "month-as-a-year" method which produced climatic factors which would apply if the climate for a given month were instead the year round climate. These monthly numbers, once normalized, provided the climate-based temporal profile. The improvements arising from the use of the month-as-a-year method are due to the fact that it relies on temperature, and precipitation inputs, in addition to wind. The ARBWEQ further modified the temporal profile calculation, by also adding nonclimate-based temporal factors. The month-as-a-year method in the ARBWEQ produces pronounced curves with small climatic factors (resulting in lower emissions) in the cool, wet and more stagnant periods, and large climatic factors (and higher emissions) in the hot, dry, and windy periods. The U.S. EPA method yields gentler profiles, which are shifted into the cooler and wetter months from the ARBWEQ profiles. The 1989 CARB methodology established one erosive wind energy distribution statewide. This resulted in an unrealistic, nearly flat distribution, with very little seasonality. Therefore, the ARBWEQ month-as-a-year method provides a more realistic picture of the windblown dust temporal profile (see supplemental documentation[2] for comparison curves, and supporting references).

7.2.3 Nonclimate-Based Improvements in the ARBWEQ

Among the nonclimate-based factors that influence windblown agricultural emissions are soil type, soil structure, field geometry, proximity to wind obstacles, crop, soil cover by crop canopy or post harvest vegetative material, irrigation, and replanting of the post harvest fallow land with a different crop. CARB staff have attempted to correct many of these limitations in the ARBWEQ. Many of the corrections are temporally based and rely upon the establishment of accurate crop calendars to reflect field conditions throughout the year. The long-term irrigation-based adjustment to erodibility, due to soil cloddiness, is not temporally based, and is therefore applied for the entire year.[11] The change in erodibility varies based on soil type, but often results in a reduction in the tons per acre value for irrigated crops of about one-third.

Crop Calendars: Quantifying Temporal Effects. Factors such as crop canopy cover, post harvest soil cover, irrigation, and replanting to another crop have a major effect on windblown emissions. Estimating the effects of these factors requires establishing accurate crop calendars. The planting and harvesting dates are principal components of the crop calendar. The list of references consulted to establish the planting and harvesting dates is included in the supplemental documentation.[2]

Each planting month for a given crop was viewed by CARB staff as a separate cohort (maturation class). Since a single planting cohort may be harvested in several months, each cohort was split into cohort-plant/harvest date pairs. The cohort-plant/harvest date pairs were then assigned based upon a first-in-first-out ordering. The fraction of the total annual crop assigned to a given cohort-plant/harvest date pair was derived by multiplying the fraction of the total annual crop planted in a given month (cohort) by the fraction of the cohort harvested in a given month. The fraction of a cohort-plant/harvest date pair that has been planted, but not harvested at any given time, is termed the growing canopy fraction, or GCF (although the canopy may or may not actually be increasing at any given time). The growing canopy fraction determines the fraction of the acreage that will have the crop canopy factor applied to its emission calculations. The acreage that is not assigned to the growing canopy fraction is the postharvest/preplant (PHPP) acreage. The PHPP acreage will have the post harvest soil cover, and replanting to a different crop factors applied when calculating its emissions. The effect of using cohort-plant/harvest date pairs is to blend the crop canopy, soil cover, replanting, and irrigation effects over both the planting and harvesting periods. This approach provides a more realistic estimate of the temporal windblown emissions profile during these periods. All of the monthly factor profile adjustments described below are calculated for each month of the year, for each cohort-harvest/plant date pair, for each crop, for each county.

Adding a Short-Term Irrigation Factor for Wetness. This adjustment takes into account the overall soil texture, number of irrigation events, and fraction of wet days during the time period[11] (one month for the purposes of the CARB inventory). The list of references consulted to establish the irrigation profiles is included in the supplemental documentation.[2] The irrigation factor for months in which irrigations take place will typically be greater than 0.80. In other words, the irrigations will result in a reduction in erodibility of less than 20%. This is only an estimate for a typical case during the growing season. When averaged over the year, the overall reduction in erodibility is lower.

Replacement Factors to Address Problems with the Vegetative Soil Cover Factor in the WEQ. According to CARB, there are many problems with the vegetative soil cover factor, V,. For example, this factor is applied to the acreage year round, even during the growing season, and ignores the effect of disk-down and other land preparation operations on post harvest vegetative soil cover. The factor also does not account for canopy cover during the growing season. In addition, the WEQ was derived based on agricultural practices typical of the Midwestern United States. Crops such as alfalfa have full canopy cover for nearly the entire year. There is also a large amount of acreage that is used for more than one crop per year, and there was no provision in the vegetative soil cover factor for estimating the effects on emissions of this replanting. Whether the land is to be immediately replanted to a different crop, or is going to remain fallow until the next planting of the same crop, it is common practice to disk under the harvested crop within a month or two of harvest. The vegetative soil cover factor for the most part assumes that the post harvest debris remains undisturbed. References to support this agricultural practice are included in the supplemental documentation.[2] CARB staff replaced the vegetative soil cover factor in the ARBWEQ with the three adjustments discussed below to approximate the effects on windblown agricultural PM emissions of: (a) crop canopy cover during the growing season; (b) changes to post harvest soil cover; and (c) post harvest planting of a different crop on the harvested acreage.

<u>Crop Canopy Factor.</u> Crop canopy cover is the fraction of ground covered by crop canopy when viewed directly from above. USDA-ARS staff provided CARB with methodology from the RWEQ for estimating the effects of crop canopy cover on windblown dust emissions.[7] The soil loss ratio (SLRcc) is defined as the ratio of the soil loss for a soil of a given canopy cover divided by the soil loss from bare soil. SLRcc is the factor which is multiplied by the erodibility to adjust the erodibility for canopy cover. The greater the canopy cover, the smaller the SLRcc, and the greater the reduction in erodibility. SLRcc defines an exponential curve that demonstrates major differences in the erodibility reduction for the range of zero to 30 percent canopy cover (typically achieved within a few months after planting). Thereafter, reductions occur much more slowly, and eventually the curve flattens out. This results in a rapid decrease in emissions during the first few months following planting, until the emissions are only a

very small fraction of the bare soil emissions. The canopy cover then will remain, and the windblown emissions will consequently stay very low until harvest. Senescence effects (late growing season reduction in canopy) have been excluded from this model, and the rationale for that exclusion has been discussed in the supplemental documentation.[2]

Post Harvest Soil Cover Factor. Post harvest soil cover is the fraction of ground covered by vegetative debris when viewed directly from above. USDA-ARS staff provided CARB with methodology from the RWEQ for estimating the effects of post harvest soil cover on windblown dust emissions.[7] The soil loss ratio (SLRsc) is defined as the ratio of the soil loss for a soil of a given soil cover divided by the soil loss from bare soil. SLRsc is the factor which is multiplied by the erodibility to adjust the erodibility for post harvest soil cover. The greater the post harvest soil cover, the smaller the SLRsc, and the greater the reduction in erodibility. The list of references consulted to establish the post harvest soil cover profiles is included in the supplemental documentation.[2]

Post Harvest "Replant-to-Different-Crop" Factor. As discussed above, the vegetative soil cover factor does not include any adjustments for harvested acreages that are quickly replanted to a different crop. This multiple cropping is very common in California, and has been accounted for in this methodology by removing from the inventory calculation the fraction of the harvested acreage that is replanted, at the estimated time of replanting. This removed fraction is based on information provided by agricultural authorities (see reference list in supplemental documentation[2]). The net result of the application of the fraction is that the post disk-down acreage (one to two months after harvest), and resultant emissions, is reduced by the fraction of harvested acreage converted to a new crop.

Bare and Border Soil Adjustments. Most fields will have some cultivated areas that are barren. These bare areas could be due to uneven ground (e.g., water accumulation), uneven irrigation, pest damage, soil salinity, etc. Most fields will have some type of border. In some cases there is a large barren border, in other cases it is overgrown with vegetation. Many border areas are relatively unprotected, and prone to wind erosion. CARB staff established approximate fractions of cultivated acreage that would be barren and border areas, respectively. These barren and border acreage adjustments result in emission increases disproportionate to the acreage involved. The reason that the bare acreage-based increase is so large is that the bare acreage does not have either a crop canopy or post harvest soil cover factor applied. The same reasons apply to the border adjustment, but the border region is also assumed not to be irrigated. Therefore, no irrigation factor (wetness), and no long-term irrigation adjustment to erodibility (cloddiness) are applied. No border adjustment was applied to the pasture acreage, since pasture areas frequently lack a barren border.

Temporal Activity. For the 1989 CARB methodology, the temporal profile was based on an estimated statewide erosive wind energy profile. The profile, implemented in the ARBWEQ included wind, precipitation and temperature climatic effects, along with the addition of the effects of crop canopy, postharvest soil cover, postharvest replanting to a different crop, and irrigation. In addition, the inclusion of bare ground and field border effects also adjusted the profile in the ARBWEQ. The profile produced for the ARBWEQ is no longer a separate profile applied to annual emissions, but is now an intermediate output produced during the estimation of annual emissions.

7.3 Demonstrated Control Techniques

The emission potential of agricultural wind erosion is affected by the degree to which soil management and cropping systems provide adequate protection to the exposed soil surface during exposure periods. Table 7-1 presents a summary of demonstrated control measures and the associated PM10 control efficiencies. It is readily observed that reported control efficiencies for many of the control measures are highly variable. This may reflect differences in the operations as well as the test methods used to determine control efficiencies.

Table 7-1. Control Efficiencies for Control Measures for Agricultural Wind Erosion[13-17]

Control measure	PM10 Control Efficiency	References/comments
Artificial wind barrier	64-88%	U.S. EPA, 1992. Assumes a 50% porosity fence.
	54-71%	Grantz et al, 1998. Control efficiency is for a wind fence.
	4-32%	Bilbro and Stout, 1999. Control efficiency based upon reduction in wind velocity by a wind fence made from plastic pipe with a range of optical density of from 12% to 75%.
Cover crop	90%	Washington State Univ., 1998.
Cross-wind ridges	24-93%	Grantz et al, 1998. Control efficiency is for furrows.
	40-80%	Washington State Univ., 1998.
Mulching	20-40%	Washington State Univ., 1998. Control efficiency is for straw.
Trees or shrubs planted as a windbreak	25%	Sierra Research, 1997. Control efficiency is for trees.

7.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 7-2. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

Table 7-2. Example Regulatory Formats for Agricultural Wind Erosion

CAPCOA				Maricopa County, AZ			
Control measure	Goal	Threshold	Agency	Control measure	Goal	Threshold	Agency
Requires producers to draft and implement fugitive dust plan with approved control methods	Limits fugitive dust from agricultural sources		SJVAPCD Rule 8081 11/15/2001	Dust suppressants, gravel, install shrubs/trees	Limit fugitive dust plume to 20% opacity	Commercial feedlot/livestock area; shrubs/trees 50ft-100ft from animal pens; compliance with stabilization limitation	Maricopa County Rule 310.01 02/16/2000
Exemption from Rule 403 gen. reqs.	Limit PM10 Levels to 50 ug/m^3	Voluntary implementation of district approved conservation practices and complete/maintain self-monitoring plan	SCAQMD Rule 403 12/11/1998 (Applies to Coachella Valley Apr. 2004)				
Requires dust plan that contains procedures assuring moisture factor between 20%-40% for manure in top 3" of occupied pens and outlines manure management practices and removal	Reduce fugitive dust from livestock feed yards		ICAPCD Rule 420 8/13/2002	Record keeping for all ctrl measure taken	Ensure that appropriate ctrl measures are implemented and maintained	All ops subject to Rule 310.01, provided within 48 hrs of ctrl officer request	Maricopa County Rule 310.01 02/16/2000

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

(Note: The Clark County website did not include regulatory language specific to agricultural wind erosion at the time this chapter was written.)

7.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

The following table summarizes the compliance tools that are applicable to agricultural wind erosion.

Table 7-3. Compliance Tools for Agricultural Wind Erosion

Record keeping	Site inspection/monitoring
Land condition by date (e.g., vegetation; furrowing of fallow land; soil crusts), including residue management and percentages; meteorological log; establishment/ maintenance of wind breaks.	Observation of land condition (crusts, furrows), especially during period of high winds.

7.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from agricultural wind erosion. A sample cost-effectiveness calculation is presented below for a specific control measure (mulching) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Agricultural Wind Erosion

Step 1. Determine source activity and control application parameters.

Field size (acres)	320
Control Measure	1,000 lb mulch per acre
Control application/frequency	Once post-harvesting
Control Efficiency	30%

The field size is an assumed value, for illustrative purposes. Mulching at a rate of 1,000 lbs per acre has been chosen as the applied control measure. The control application/frequency and control efficiency are default values provided by WSU, 1998.[16]

Step 2. Calculate Emission Factor. The PM2.5 and PM10 emission factors are obtained from MRI, 1992,[15] with a default PM2.5/PM10 ratio of 0.25.

PM2.5 Emission Factor	21.7 (lb/acre)
PM10 Emission Factor	86.6 (lb/acre)

Step 3. Calculate Uncontrolled PM Emissions. The emission factors (given in Step 2) are multiplied by the field size (under activity data) and then divided by 2,000 lbs to compute the annual emissions in tons per year, as follows:

Annual emissions = (Emission Factor x Field Size)/2,000

- Annual PM10 Emissions = (86.6 x 320) /2,000 = 13.9 tons
- Annual PM2.5 Emissions = (21.7 x 320) /2,000 = 3.5 tons

Step 4. Calculate Controlled PM Emissions. The uncontrolled emissions estimate (calculated in Step 3) is multiplied by the percentage that uncontrolled emissions are reduced, as follows:

Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency), where CE = 30% (as seen under activity data)

For this example, we have selected conservation tilling as our control measure. Based on a control efficiency estimate of 30% , the annual controlled emissions are calculated to be:

Annual Controlled PM10 emissions = (13.9 tons) x (1 – 0.3) = 9.7 tons
Annual Controlled PM2.5 emissions = (3.5 tons) x (1 – 0.3) = 2.4 tons

Step 5. Determine Annual Cost to Control PM Emissions.

The Annualized Cost is calculated by multiplying the number of acres by the cost per acre. The default cost is $40 per acre (WSU, 1998)[16]:

Annualized Cost = 320 x 40 = $12,800

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost-effectiveness = Annualized Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = $12,800/ (13.9 – 9.7) = $3,100/ton
Cost-effectiveness for PM2.5 emissions = $12,800/ (3.5 – 2.4) = $12,300/ton

7.7 References

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